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ECL 270

A DISASTER IN THE MAKING

It took only fifteen seconds for the massive south arm of the Quebec Bridge to fall into the St. Lawrence River in 1907, but the prelude to the catastrophe began years before.

John Tarkov

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At five-thirty on the afternoon of August 29, 1907, a steelworker named Ingwall Hall was perched high on the partially constructed south cantilever arm of the Quebec Bridge, a few miles from Quebec City. The bridge was to have a span of eighteen hundred feet when completed-the longest in the world. The first whistle signaling the end of the workday had just blown, and Hall was waiting out the few minutes before the final whistle that would send the men on the structure home for the night.

Instead of the final whistle, the workers heard a loud report, like a cannon shot. Two compression chords in the south anchor arm of the bridge had failed, either by the rupture of their latticing or by the shearing of their lattice rivets, and as the distress of mortally tortured steel spread through the entire superstructure, the nineteen thousand tons of the south anchor and cantilever arms and the partially completed center span thundered down onto the banks of the St. Lawrence River and into the water the bridge had been designed to cross. One eyewitness likened the collapsing columns to "ice pillars whose ends were rapidly melting away."

Swallowing water and fighting the river's sudden turbulence, Hall had to struggle in order to breathe. After a few long minutes, a rescue boat reached Hall, and he was dragged aboard. He had lost two fingers, but of the eighty-six men on the bridge when it went down, he was one of only eleven who survived.

No bridge collapses quickly. Just as the safe completion of a bridge is measured in years, the failure of a bridge can be reckoned in the same way. Though the chaotic physical dismemberment of the south arm of the Quebec Bridge took no more than fifteen seconds, the more orderly prelude to the catastrophe began long before.

It began in the summer of 1897, when the consulting engineer Theodore Cooper attended the annual convention of the American Society of Civil Engineers in Quebec City. A former director of the society, Cooper was one of the most respected bridge builders of the time. He made an excursion to the proposed site of the Quebec Bridge and within a week expressed an interest in giving the Quebec Bridge Company the benefit of his expertise.

Cooper's tender of interest was hardly unbidden. The Quebec Bridge Company had been sounding out American bridge engineers as consultants because its own chief engineer, Edward A. Hoare, had never worked on a bridge with a span longer than three hundred feet. Cooper was a proud, confident man, fiercely devoted to his calling. He had been graduated as a civil engineer from Rensselaer Institute (now Rensselaer Polytechnic) in 1858 at the age of nineteen. Enlisting in the Navy in 1861, he served as an assistant engineer of the gunboat Chocura for the last three years of the Civil War, then moved on to a teaching post at the United States Naval Academy. After a tour of duty in the South Pacific, he resigned from the Navy in July 1872. In May of that year, Capt. James Eads appointed Cooper the inspector of steel manufacturing for Ead's most important engineering work, the St. Louis Bridge.

If the Navy laid the groundwork for Cooper's career, the St. Louis Bridge launched it along a high trajectory. Captain Eads moved

Cooper up quickly, placing him in charge of erection at the bridge, which was the most ambitious use of the cantilevered method of erection yet attempted. Cooper performed his duties admirably—once going without sleep for sixty-five hours during a crisis, another time wiring Eads at midnight to warn him that the arch ribs were rupturing, a potentially disastrous condition that was remedied by following the instructions Eads immediately wired back. Upon completion of the work in 1874, Cooper found himself much in professional demand. By 1879, after resigning as the superintendent of Andrew Carnegie's giant Keystone Bridge Company in Pittsburgh, Cooper was able to set up as an independent consulting engineer in New York.

The projects he undertook there were notable and prestigious. His works included the Seekonk Bridge in Providence, the Sixth Street Bridge in Pittsburgh, and the Second Avenue Bridge in New York. He moved through the most rarefied atmosphere of his profession, but unlike his mentor Eads, he never oversaw a truly heroic masterwork. The Quebec Bridge, viewed in that light, was irresistible to Cooper. He said the bridge would be his last work. It would stand as the crowning achievement to an elegant career.

Almost two years would go by before Cooper's affiliation with the Quebec Bridge Company became formal. The financially troubled company had a history of moving slowly—or not at all. Incorporated by an Act of Parliament in 1887, it had accomplished virtually nothing in its first eleven years. In March 1899 officials of the company met with Cooper in New York and arranged for him to review the bids for the long-awaited bridge contracts. All prospective contractors' plans and tenders were sent to him, as well as the clear message that he should keep in mind the weak financial position of the Quebec Bridge Company.

The Quebec Company had been in close touch with the Phoenix Bridge Company of Phoenixville, Pennsylvania, since 1897, and the Phoenix Company had already submitted preliminary plans for the bridge. Now that the bidding was open, the Quebec Company's desire to give the Phoenix Company the contract for the superstructure was barely concealed.

On April 14, 1899, John Sterling Deans, the chief engineer of the Phoenix Bridge Company, wrote to Edward Hoare, his counterpart in Quebec: "Dear Mr. Hoare--Mr. Szlapka [Phoenix's chief design engineer] and I were with Cooper the greater part of yesterday, and you will be glad to learn that there was not a single vital or important criticism or mistake found in our plans...Mr. Cooper, however, somewhat upset me, by making the following remark, which of course I understood was entirely personal and without any full knowledge of the situation. He said: 'Well, Deans, I believe that all of the bids will probably overrun the amount which the Quebec Bridge Company can raise, and that the result will be...that all of the bids will be thrown out and a new tender asked on revised specifications and plans.' Mr. Cooper undoubtedly desires to be perfectly fair, but...does not fully understand the situation. I trust, therefore, that you will give his report the most careful scrutiny, and get it in the right shape before it is submitted."

There were more collegial letters between Phoenixville and

Quebec, and both Deans and Hoare stayed in close touch with Cooper. Later Cooper would maintain that no pressure had been brought to bear on him. In any event, on June 23, 1899, he sent his findings to the Quebec Bridge Company. "I therefore hereby conclude and report," he wrote, "that the cantilever superstructure plan of the Phoenix Bridge Company is the 'best and cheapest' plan and proposal."

Those three words--"best and cheapest"--became a touchstone for Cooper in his approach to the bridge. His subsequent letters to Quebec and Phoenixville are seasoned with references to the fiscal consequences of major design decisions. None of the parties involved ever placed costs before safety outright, but their aim was clearly to build a bridge that could bear the twin loads of its own mechanical burden and the Quebec Bridge Company's financial burden.

The Quebec Company had no cause to be dissatisfied with Cooper's scrupulous concern for its ledger books--and had every reason to be confident of his ability to oversee the building of a good bridge. On May 6, 1900, Cooper was appointed the company's consulting engineer for the duration of the work. He had become, finally, the master builder on a project of historic magnitude.

Five days before his formal appointment on May 1, Cooper exercised his authority by recommending that the span of the bridge be lengthened from sixteen hundred feet to eighteen hundred feet. His explanation for this major design change revealed an attentiveness to both engineering and expense. Piers constructed in deeper water would be subject to the heavy ice floes of the main channel. Closer to shore, they would be less vulnerable--and quicker to build, speeding up the completion of the entire work by at least one year. To keep down the increased cost of steel in the superstructure for an eighteen-hundred-foot span, Cooper recommended another major design change: modified specifications that would allow for higher unit stresses. [See Exhibit A1]

His recommendations were approved at Quebec almost as a matter of course. And then, for the next three years--as work proceeded on the substructure, the anchorages, and the approach spans--practically nothing was done to prepare for the engineering difficulties posed by the eighteen-hundred-foot span and the higher allowable stresses.

Once again, money was the root of inaction. Short of funds as usual, the Quebec Bridge Company was making no promises to anybody about its capacity to pay for the bridge's superstructure once the preliminary work was done. For all the goodwill between Phoenixville and Quebec, the Phoenix Bridge Company was politely declining to enter into a contract until payment might be assured.

And so, while the huge size of the bridge cried out for preliminary tests and research studies, none were conducted during the long slack period between 1900 and 1903. It was not in the interests of the Phoenix Bridge Company to go out-of-pocket on research costs it might never recoup, and it was plainly impossible for the Quebec Bridge Company to provide the funds. An unspoken assumption became necessary instead: Theodore Cooper's experience and authority were sufficient to confer success upon the untested work.

Then in 1903 the Canadian government guaranteed a bond issue of

$6.7 million to pay for the work. With that, the torpor enveloping the project turned into humming activity. Phoenix and Quebec entered into serious contract discussions while design engineers and draftsmen struggled to meet the urgent demand for detailed drawings.

Three years of opportunity for deliberate preparation had been lost. In the rush to provide drawings so that the steel for the bridge could be fabricated with little loss of time, there was no recomputation of assumed weights for the bridge under the revised specifications. It was an oversight of critical importance, and Theordore Cooper did not intervene. He decided to accept the theoretical estimates of weight that the Phoenix Bridge Company had provided.

During the three languid years that preceded the project's lurch into progress, Cooper visited the site of the bridge three times. His third visit, in May 1903, when he was sixty-four, would be his last. After that, he would decline requests that he come to Quebec. His health was poor, he said, and his physician had advised him not to travel. From that point on, he would oversee the construction of the world's longest spanning bridge from his office in New York.

Cooper's health may indeed have been fragile, but he was hardly an invalid, commuting almost daily to his office at the foot of Manhattan Island from his home on West Fifty-seventh Street. The only specific references to illness in his letters to Quebec and Phoenixville cite "the grippe" and "fatigue" as his reasons for not being able to be there.

In fact, he had never much appreciated being there in person as a consulting engineer. He regarded on-site visits as unproductive and largely devoted to atmospherics. From his earliest days in private practice, Cooper had insisted on a clause in his contract that limited his on-site responsibilities to a maximum of five days a month. When the Quebec Bridge Company's secretary, Ulric Barthe, at one point brought Cooper's attention to that understanding, Cooper replied that the five days were not an obligation but a limit, implying that it was a limit not to be abused. With his health now weakened, the five-day limit became academic.

The question of his health also caused Cooper to offer what amounted to a pro forma resignation in 1904. On a visit to New York, S. N. Parent, the president of the Quebec Bridge Company, asked Cooper when he might see him in Quebec again. Cooper's answer was never. He then asked to be relieved of his responsibilities, but Parent would not hear of it. A short time later Cooper made the same offer to John Deans of the Phoenix Bridge Company, who also refused to treat it seriously. The matter was laid to rest, and Cooper refrained from pressing it. Feeling, as he later said, "a pride and a desire to see this great work carried through successfully, I took no further action."

In the summer of 1903, while Cooper was still well enough to travel, his pride in the great work took him to Ottawa. He was incensed. Collingwood Schreiber, the chief engineer of the Department of Railways and Canals, had suggested that the department hire its own consulting bridge engineer to review and correct the detailed drawings

of the Quebec Bridge—after Cooper had seen them—and then submit them to Schreiber for final approval. Robert Douglas, an engineer in Schreiber's department, had reviewed Cooper's new specifications for the eighteen-hundred-foot-span bridge and had criticized the high unit stresses. "Considering that the American government in several cases appointed four or five engineers to consider and determine unit stresses of unexampled magnitude," Douglas would say later, "I thought that this matter was too important to be left to the judgment of Mr. Cooper." But confidence in Cooper was the byword just then, and foresight was at a premium.

Upon learning of Schreiber's proposal, Cooper wrote angrily to Quebec: "This puts me in the position of a subordinate, which I cannot accept." His brisk discussions with Schreiber in Ottawa yielded a decidedly one-sided compromise, much to the relief of Cooper's worried colleagues in Quebec and Phoenixville. It was agreed that plans and specifications would pass from Cooper to Schreiber for final approval; as it would turn out in practice, Schreiber's initials could just as well have come from a rubber stamp.

"I think," Cooper wrote to Hoare upon his return from Ottawa, "this will allow us to go on and get the best bridge we can, without putting metal where it will do more harm than good." By now, whether he wanted it or not initially, Cooper had attained virtually absolute authority over the engineering of the Quebec Bridge. He would say later that the burden had been imposed upon him by the circumstances, and that it was an onerous one. But in 1903 he had journeyed in haste to Ottawa to block Schreiber's attempt to have drawings independently reviewed; in 1904 he had quickly acceded to the protestations of Deans and Parent that he not resign; and in 1905 he insisted that a young, recently graduated engineer be installed at Quebec to serve, in effect, as his eyes and ears on the bridge.

The young engineer's name was Norman McLure, and though nominally he answered to both Cooper and Hoare, he was in fact Cooper's personal representative, communicating with Cooper frequently. McLure's intelligence, energy, and loyalty suited Cooper well. He was well trained and well recommended, and he had enough technical competence to keep Cooper accurately informed and to execute Cooper's instructions, but not nearly enough experience to act without Cooper's authority.

The practical effect of all this, after the contract between Quebec and Phoenix was signed and erection of the superstructure got under way late in the summer of 1904, was to leave the day-to-day, hands-on building of the most technically ambitious bridge project in the world to a group of men utterly unprepared to grasp the scope of the work. No one at the site knew enough about what he was doing to act with authority. Everything of import was referred to Cooper.

Work on the superstructure proceeded uneventfully at first. The few difficulties that occurred were minor. The first sign of potentially serious trouble surfaced in 1906.

The best opportunity for the critical computation of weights, during the waiting period from 1900 to 1903, had long since been missed, but early in 1905 the shop drawings of the south anchor arm

were practically complete, and it would have been possible to recompute the weight of the arm to within a few percentage points of its actual weight. Neither the Phoenix Bridge Company nor Theodore Cooper bothered to do it—now for the second time.

On February 1, 1906, they began to pay the price. Cooper received a report from E. L. Edwards, the Phoenix Bridge Company's inspector of materials, revealing that the actual weight of steel put into the bridge had far exceeded the original estimated weight. (By June the projected weight for the complete structure would have to be raised from sixty-two to seventy-three million pounds.) Cooper concluded that the increase in the already high stresses, due to the error reported by Edwards, was between 7 and 10 percent.

By this time the south anchor arm, tower, and two panels of the south cantilever arm had been fabricated, and six panels of the anchor arm were already in place. Cooper decided that the increase in stresses was safe, and he permitted work to continue. The only alternative would have been to start building the bridge all over again.

By the summer of 1907 the consequences of allowing the bridge's actual dead load to go uncalculated for so long began to show up on the structure itself, in the lower chord compression members—the lower outside horizontal pieces running the length of the bridge.

On June 15 McLure wrote to Cooper: "In riveting the bottom chord splices of [the] south anchor arm, we have had some trouble on account of the faced ends of the two middle ribs not matching...This has occurred in four instances so far, and by using two 75-ton jacks we have been partly able to straighten out these splices, but not altogether."

Cooper replied: "Make as good work of it as you can, It is not serious. It would be well...in future work to get the best results in matching all the members before the full strains [forces] are brought upon them."

When work on the central, suspended span began in July—as the span crept out over the river—the rapidly increasing stresses on the compression members farther back became intolerable. The instability of built-up, latticed compression members in a major work under construction was poorly understood then, so key portions at the ends of the Quebec Bridge's weight-bearing lower chords were still unriveted, even as the stresses upon them grew insupportable with the steady outward advance of the span.

By early August the end details of the compression chords began to show signs of buckling. On August 6 McLure reported to Cooper that lower chords 7-L and 8-L of the south cantilever arm were bent. Cooper was troubled. He wired back with instructions, and with the almost plaintive question: "How did bend occur in both chords?"

On August 12 McLure informed him that the splice between lower chords 8-L and 9-L was now bent as well. Cooper's concern grew, but it was not shared in Phoenixville. Chief Engineer Deans insisted that chords 7-L and 8-L had already been bent when they left the shop. McLure insisted that they only began to show deflection after being installed on the bridge. The debate over chords 7-L and 8-L occupied

the greater part of August. Meanwhile work continued, and the stresses on the lower chords grew.

On August 20 chords 8-R, 9-R and 10-R showed distortion. On August 23 the joint between chords 5-R and 6-R showed a half-inch offset. The bend in chord 8-R was increasing. The bridge was collapsing with glacial slowness, but no one—not even Cooper, for all his concern in the face of the Phoenix Bridge Company's almost cavalier attitude—appreciated fully what was happening. (See Exhibit A2)

On August 27 the crisis should have been obvious to all. A week before, chord 9-L of the south anchor arm had been only three-quarters of an inch out of line. On the morning of August 27 McLure measured it again. The deflection was now two and one-quarter inches. McLure wrote to Cooper immediately. Had he been more experienced, he might have sent a telegram, the way a younger Theodore Cooper had once wired Captain Eads at midnight years before.

As word of what had happened to chord 9-L of the anchor arm swept the bridge, gusts of anxiety swept along with it. By the end of the day B. A. Yenser, the Phoenix Company's general foreman on the bridge, decided to suspend work, saying that he feared for his own life and the lives of the men under his charge. The next morning he changed his mind and ordered work to continue. Chief Engineer Hoare of the Quebec Company endorsed this decision—there is some evidence that he may have requested it. He saw no immediate danger, and he was afraid that stopping work then might mean that it would not resume until spring.

Officials of the Phoenix Bridge Company continued to insist that all the bends detected in the lower chord members had been present before installation. They made no effort at all to explain how the deflection of chord 9-L had grown by an inch and a half in the past week.

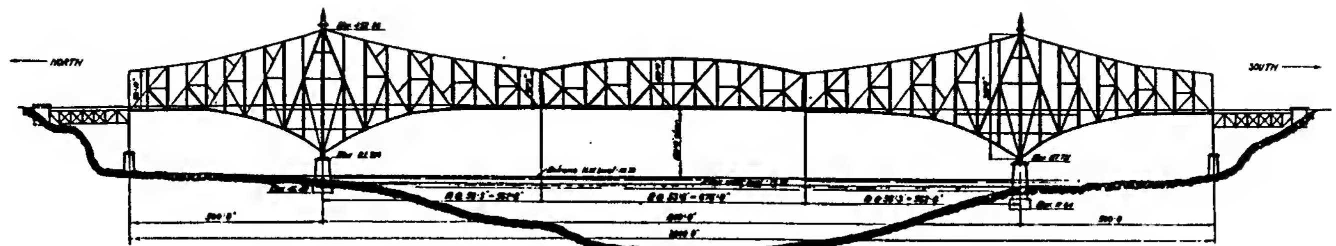
Fear was everywhere on the bridge on August 28, while the men in charge at the site were paralyzed by a vacuum of authority. Hoare, the Quebec Company's responsible engineer on the project, was technically unqualified—and thus unable—to take command. After much discussion, he dispatched McLure to New York to brief Cooper in person.

Shortly before 11:30 a.m. on August 29, Theodore Cooper arrived at his Manhattan office and found Norman McLure waiting for him. McLure's letter of August 27 had arrived as well. Cooper read it, spoke briefly with McLure, and at 12:16 p.m. he sent a terse telegram to Phoenixville that read: "Add no more load to bridge till after due consideration of facts. McLure will be over at five o'clock."

Cooper was unaware that work was still going on at Quebec. He was under the impression, based on McLure's letter, that construction had stopped two days before. In his haste to catch a train to Phoenixville, McLure neglected to wire Cooper's decision to Quebec as he had promised to do, and so work continued through the afternoon.

Cooper's telegram reached Phoenixville at about 3:00 p.m. John Deans read it—and disregarded it. The workers stayed on the bridge. When McLure arrived at five o'clock, Deans and Peter Szlapka met with

him. They agreed to meet again in the morning, when a letter from Phoenix's field engineer at Quebec was due to arrive. The letter would support the Phoenix Company's position that the chords had left Phoenixville slightly bent but serviceable. Almost precisely as the meeting adjourned, chords 9-L and 9-R of the anchor arm buckled, and the Quebec Bridge collapsed. (See Exhibit A3)



GENERAL ELEVATION OF THE DESIGN PROJECTED BY THE PHOENIX BRIDGE COMPANY.

The cut above is an elevation of the Quebec Bridge as projected by the Phoenix Bridge Co.

Plate 5 is a photograph taken of the bridge on the 27th August, 1907, two days before it collapsed. Plates 6 and 7 show views of the wreck after the accident. The disaster was accompanied with heavy loss of life. The accident made a profound impression upon the Engineering World and, indeed, upon the general public both in Canada and in other countries. The Government at once appointed a Royal Commission consisting of Professor John Galbraith, J. G. Kerry and Henry Holgate, Chairman, to investigate and report upon the accident. An independent report was also asked from Mr. C. C. Schneider which was incorporated in the Blue Book on the inquiry. The Blue Book was very complete, the Commission having assembled most of the available data on other long span bridges, illustrated their important features, recorded the tests on large size compression members that had previously been made together with a number of tests made by the Commission on the behavior of such members under stress.

After receiving the report of the Royal Commission the Minister of Railways & Canals appointed a Board of Engineers to prepare plans and specifications for a new bridge. The Board, which was appointed on the 17th August, 1908, consisted of Messrs. Maurice FitzMaurice, M.I.C.E., of London, England; Ralph Modjeski, M.A.S. C.E., Chicago, and H. E. Vautelet, M.C.S.C.E., of Montreal, Chairman and Chief Engineer.

Mr. Vautelet prepared plans and specifications which were exhibited to intending bidders about the first of January, 1910, but the other Members of the Board did not fully approve of the plans, believing that a more practicable design could be produced and consented to tenders being called upon the design only on condition that bidders might submit tenders on their own plans if they so desired.

Exhibit A1 -- Szlapka and Cooper's final design for the ill-fated bridge, after the main span had been increased to eighteen hundred feet.

Exhibit A2 -- Six days before its collapse, the bridge reaches delicately out over the river. The first three panels of the center span extend to the left of a temporary tower.

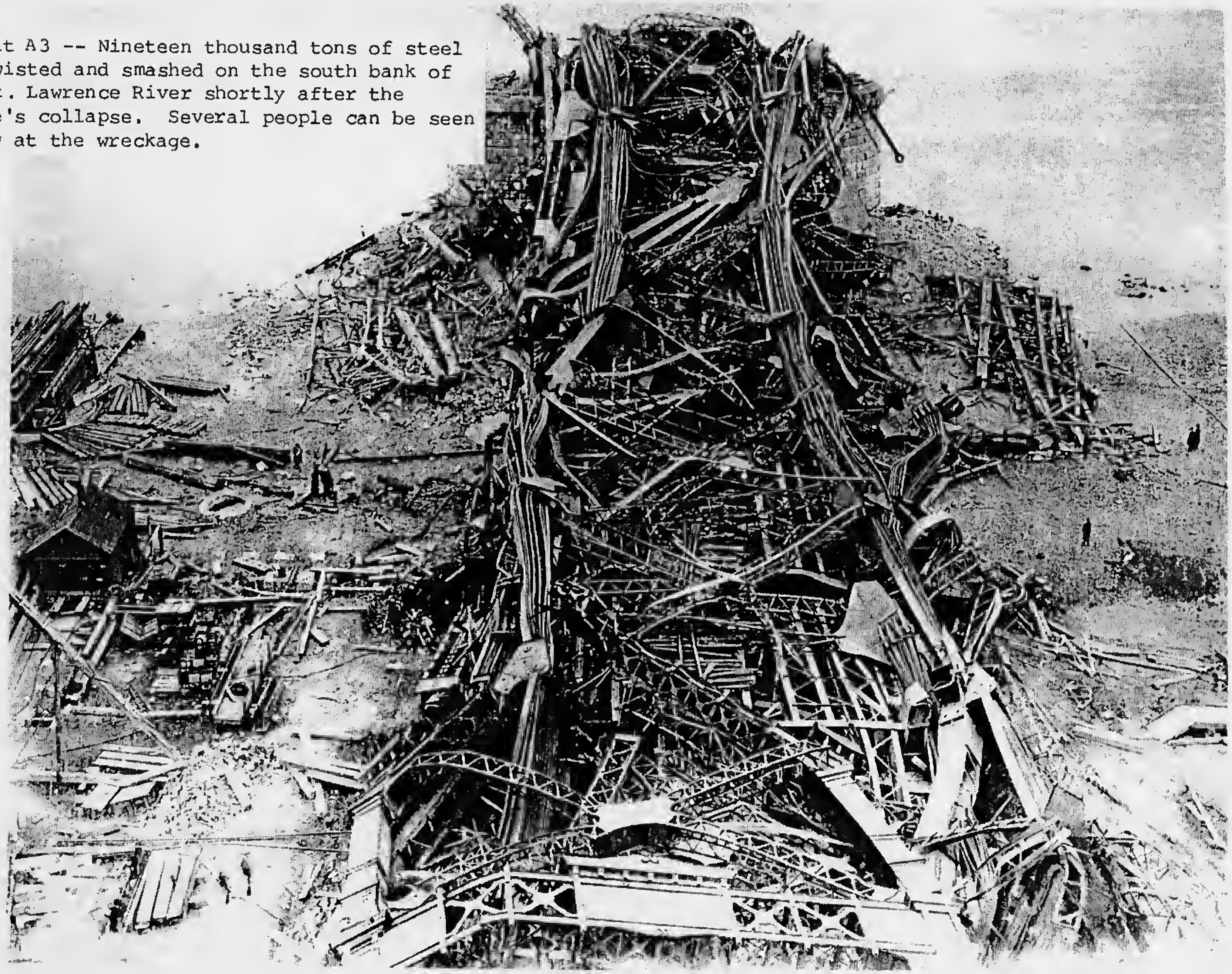


Exhibit A3 -- Nineteen thousand tons of steel lie twisted and smashed on the south bank of the St. Lawrence River shortly after the bridge's collapse. Several people can be seen gazing at the wreckage.

The members of the Royal Commission of Inquiry investigating the collapse wrote in their 1908 report, "We are satisfied that no one connected with the work was expecting immediate disaster, and we believe that in the case of Mr. Cooper his opinion was justified. He understood that erection was not proceeding; and without additional load the bridge might have held out for days."

John Deans was excoriated for his abysmally poor judgment during the final crisis, and the Quebec Bridge Company was criticized for appointing the unqualified Edward Hoare as the responsible engineer at the site. But the brunt of the blame was placed on the shoulders of Theodore Cooper and Peter Szlapka. Cooper had examined and approved Szlapka's design for the bridge. "The failure," said the commissioners, "cannot be attributed directly to any cause other than errors in judgment on the part of these two engineers...A grave error was made in assuming the dead load for the calculations at too low a value...This error was of sufficient magnitude to have required the condemnation of the bridge, even if the details of the lower chords had been of sufficient strength."

The second Quebec Bridge was completed in 1917. Weighing two and a half times more than its ill-fated predecessor, it has stood without any additional reinforcement since the day it opened. It did undergo a calamity of its own, however. In 1916 its prefabricated central span dropped into the river while being raised into place, killing eleven.

Theodore Cooper's career ended with the collapse of the first Quebec Bridge. He testified twice before the Royal Commission, speaking candidly and with some bitterness toward both the Phoenix and Quebec bridge companies. His testimony brought forth a fusillade of countercharges from officials at Phoenixville and Quebec. With that last tremor of the tragedy behind him, Cooper retired from public life. He died at home on August 24, 1919, at the age of eighty.

Several months after the disaster, a party of engineering students from McGill and Laval universities made an excursion to the site of the ruins that had been the first Quebec Bridge. There was little they could learn from the tortured steel; the Royal Commission had already pronounced it of strictly limited value to its own investigation.

What lessons the debris contained had to be gleaned on levels other than the purely technical. And if the twisted metal spelled out anything to the young engineering students as they made their way around it, the message was this: Any great bridge builder is by nature a figure of hubris. Here is what happens when hubris goes insufficiently checked by deliberation and exquisite care in the face of the little known. You may not think this could happen to you, but it can. It can happen to anyone who dares to build. It happened here to the best of them.

Bridge Failure In, Bridge Failure Out

The building of great bridges has changed since Theodore Cooper's day, but as Professor Philip J. Harris of the Department of Civil Engineering and Applied Mechanics at McGill University points out, "Human beings really haven't changed that much." Honest human error in the face of the unforeseen—or the unforeseeable—is ultimately what brings bridges down, as it did in 1940 when the overambitiously designed, four-month-old Tacoma Narrows suspension bridge over Puget Sound writhed sinuously in a high wind until it broke apart. Human error was also the underlying cause in 1967 when the seemingly sturdy, forty-year-old Silver Bridge over the Ohio River at Point Pleasant, Ohio, collapsed without warning, plunging forty-six motorists to their deaths.

The collapse of the Silver Bridge proved such an enigma to investigators that it took four years of study, using state-of-the-art technology, to determine the reason: metal fatigue had caused one eyebar to crack and fail, bringing the rest of the bridge down with it. The fatal crack was so thin that it could not have been detected in the standing structure by even the most sophisticated methods available.

Far less subtle was the collapse of the West Gate Bridge at Melbourne, Australia, in 1970. In trying to connect the main lengthwise splice of the bridge, engineers started removing bolts from the main transverse splice at midspan to correct for misalignment. Before they had taken out enough bolts to correct it, they removed so many that the bridge suddenly collapsed. "You can hardly believe," says Harris, "that anyone, let alone qualified engineers, could make such a mistake."

But while human error will be a major variable as long as human beings build bridges, improvements in other areas—more reliable materials, greatly expanded technical knowledge, a much larger pool of qualified engineers, and organizational schemes in which a number of expert opinions weigh in—have taken some of the uncertainty out of bridge work.

The most novel improvement comes as no surprise: computer technology. "Cooper and Phoenix had good analytical capabilities for their time," says Roger Dorton, who manages the Structural Office of the Ontario Ministry of Transportation and Communications, "but they lacked the speed to rerun changes and test out their assumptions. They extrapolated from smaller bridges, with no perception that with the Quebec Bridge they were getting into a new realm of knowledge."

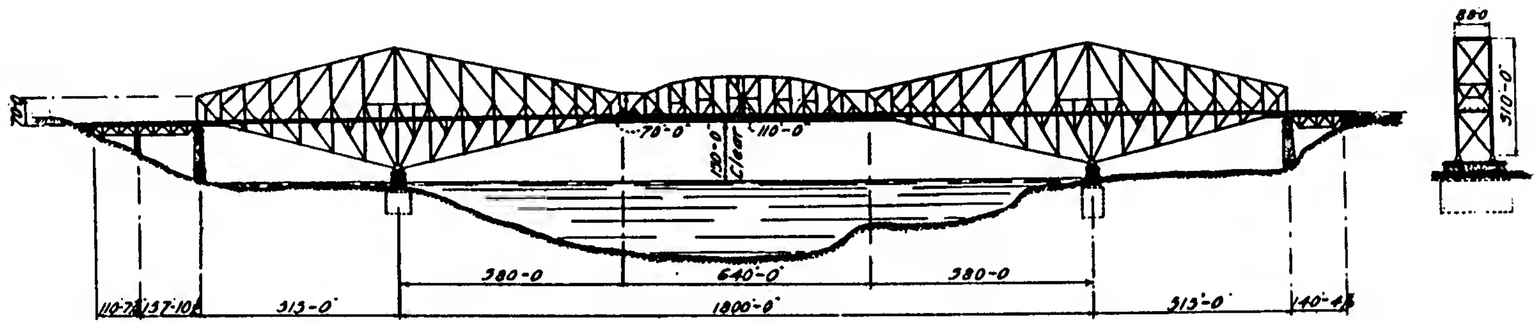
Computer modeling and analysis, however, can have its pitfalls. "It can give you a false sense of security," says Professor Emory Kemp, who heads the Program of the History of Science and Technology at West Virginia University. "With computers you can end up working along the fine edge of safety, and there may be those one or two key factors you haven't thought of." Or to paraphrase a data processing maxim: Bridge failure in, bridge failure out.

At the University of Maryland, a computer data base is being used

in the new field of forensic engineering. Founded in 1982, the university's Architecture and Engineering Performance Information Center (AEPIC) makes available information on past structural failures as a preventive tool for architects and engineers. Data are available on about thirty bridge failures.

A problem confronting AEPIC, says its director, Donald Vannoy, a professor of civil engineering at Maryland, is that the center receives a lot of verbal support but not enough information. The center has prepared a four-page data-gathering form designed to preserve the anonymity of engineers providing basic facts about failures. "No one likes to wash their dirty linen in public," says Vannoy, "but except in rare cases where the basic facts themselves are a tip-off, it's a nonsensitive form. We're hoping to double the data base in a year."

No group is more acutely aware of the calamity of bridge failures than the people who build bridges. And no one realizes better than they that the cardinal thing any bridge builder—in 1907 or 1986—must stand watch over is his own human frailty.



ST. LAWRENCE BRIDGE COMPANY DESIGN AS FINALLY APPROVED AND BUILT

Exhibit B1 -- The replacement bridge built later. This version incorporates far more massive cantilever arms and a compact suspended central span.

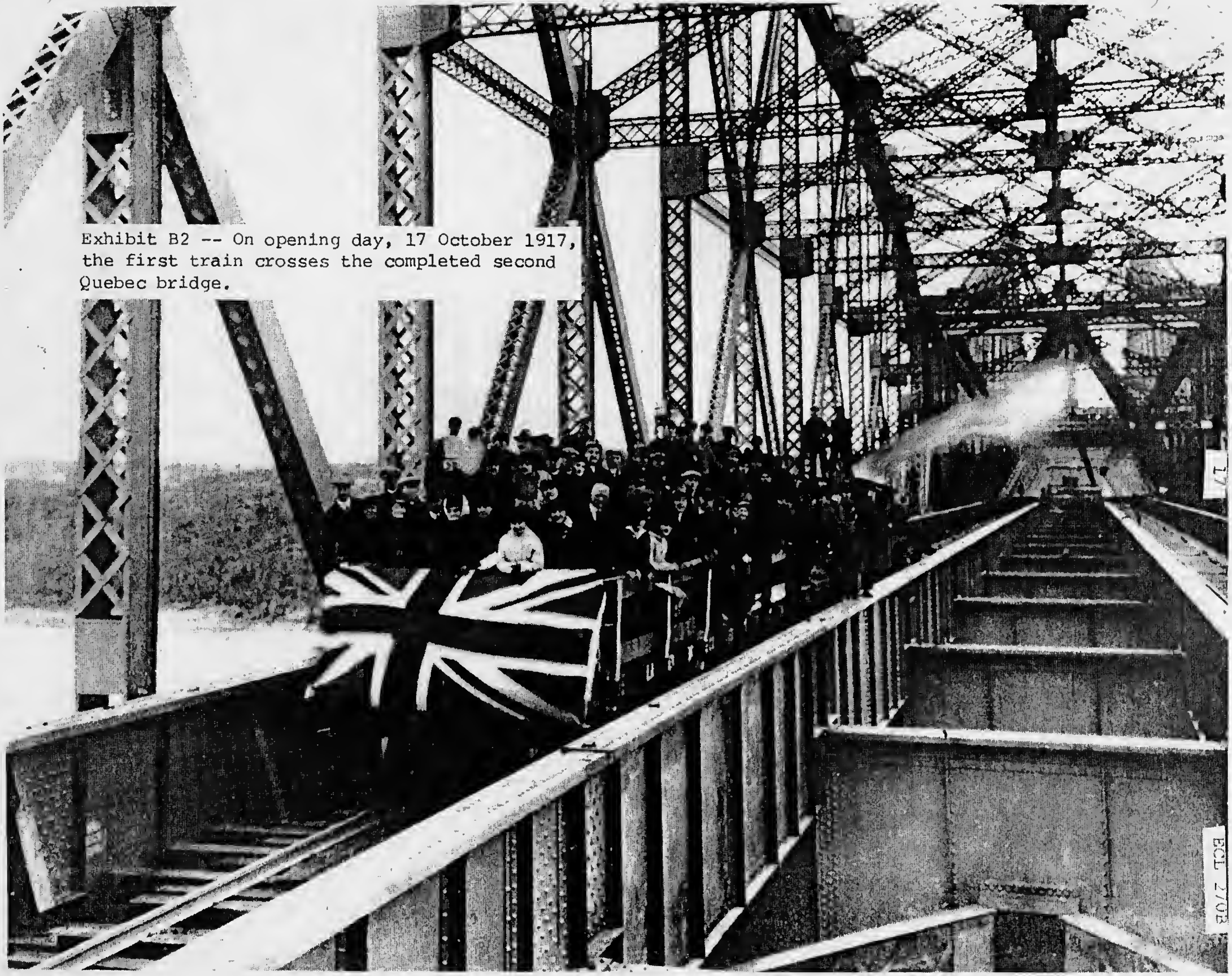


Exhibit B2 -- On opening day, 17 October 1917, the first train crosses the completed second Quebec bridge.

A DISASTER IN THE MAKING INSTRUCTOR'S NOTE

The purpose of an Insturctor's Note is to offer some suggestions which may be helpful to anyone using a case for instructional purposes. It is NOT intended, in any sense, to tell the instructor how to use the case.

At the end of Part A, there are a number of possibilities which might be pursued. Students might be asked to:

1. Estimate the magnitude of stress in the failed bridge.
2. Compare the Cooper/Eads and the McClure/Cooper relationships, e.g., write a comparative scenario of the two situations.
3. Indicate how he/she might have proceeded in the role of Cooper? In the role of McClure? In the role of Schreiber?
4. Discuss the failure to recalculate loads (and stresses) in the light of the common usage of design reviews.
5. Compare this situation with that in "Heron Road Bridge", ECL 133.
6. Compare this situation with that of the Hyatt-Kansas City "skywalk" failure.

At the end of Part B, students might be asked to:

1. Review their positions (from any of the above suggestions) in light of the additional information and the action of the Royal Commission.
2. Write the opinion he/she might have rendered if serving as a member of the Royal Commission.
3. Write a comparison of the comments on pages 14 and 15 with the well known acronym "GIGO."

Preparation of the case from AMERICAN HERITAGE OF INVENTION AND TECHNOLOGY and writing of the Instructor's Note was done by C. O. Smith.

A primary source of information is the two-volume Royal Commission of Inquiry Report of 1908. It has hundreds of pages of testimony and is an exceptionally rich source of technical data and analysis. It is available at a number of engineering libraries.